The role of vorticity fluxes in the dynamics of the Zapiola Anticyclone

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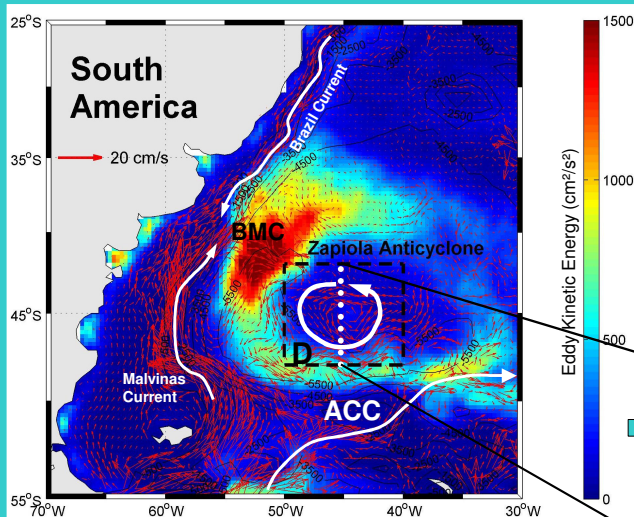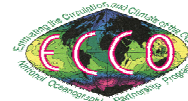*MS 300-314, 4800 Oak Grove Dr, Pasadena CA 91109-8099, Denis.Volkov@jpl.nasa.gov*

Figure 1:
The Argentine Basin, its depth-averaged circulation estimated from an ECCO2 output (red arrows), and altimetry-derived eddy kinetic energy. Bottom topography is shown every 1000 m. Abbreviations: ACC – Antarctic Circumpolar Current, BMC – Brazil-Malvinas Confluence zone, D – domain of the study.

1. Outline

The Argentine Basin in the South Atlantic Ocean (Figure 1) is one of the most energetic regions in the ocean with complicated dynamics, which plays an important role in the global climate. A number of observations have discovered an intense anticyclonic gyre of barotropic circulation (with uniform current velocity from surface to bottom, Figure 2) around the Zapiola Rise in the center of the basin. Theoretical studies have shown that the Zapiola Anticyclone represents an eddy-driven flow controlled by bottom friction. Recent advances in high-resolution global-ocean data syntheses, performed using NASA supercomputing facilities under the project Estimating the Circulation and Climate of the Ocean, Phase II (ECCO2), provide realistic simulations of the circulation and variability in the Argentine Basin (Figures 3-4). ECCO2 aims to produce accurate syntheses of all available global-scale ocean and sea-ice data at an eddy-permitting resolution with a mean horizontal grid spacing of 18 km. Using these simulations we analyzed the vorticity balance (Figures 5) and investigated what physical mechanisms drive the variability of the Zapiola Anticyclone.

Figure 2: Average vertical zonal velocity (m/s) profile across 45°W between 40°S and 50°S.

Within the Zapiola Anticyclone, between about 42°S – 48°S, zonal velocities are almost uniform from surface to bottom confirming the barotropic structure of the flow. The mass transport of the flow is highly variable with an amplitude of about 100 Sv (1Sv=10⁶ m³/s). The long term average eastward transport between 45°S and 48°S is around 95 Sv, while the average westward transport between 42°S and 45°S is approximately 60 Sv. These values agree well with observational evidence. This is a very promising result because there are a very few global models capable to realistically reproduce the Zapiola Anticyclone.

Figure 3:
In the area of the Zapiola Anticyclone the model performs well: the variations of the simulated (red curve) and altimeter-measured (blue curve) sea levels are correlated (r = 0.54, which is significant at 99% confidence). Due to geostrophic balance the anticyclone spins up when at the center of the anticyclone the sea level rises and spins down when the sea level decreases.
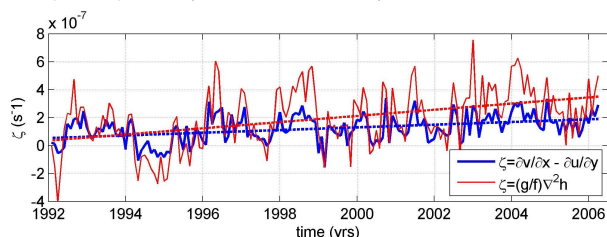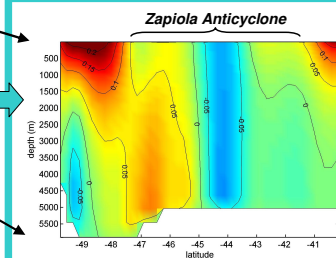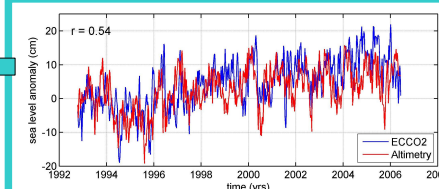
2. Circulation in the Zapiola Anticyclone

As a quantity describing the circulation in the Zapiola Anticyclone we used the vertical curl $\zeta = \partial v/\partial x - \partial u/\partial y$ of the horizontal velocity (relative vorticity) averaged over the domain D in Figure 1 within 40°W-50°W and 42°S-48°S (Figure 4, blue curve). Positive values denote an anticyclonic character of the circulation, which is dominant in the Zapiola Anticyclone, while negative values indicate a cyclonic flow. The linear trend (dashed lines) shows that from 1992 to 2006 the gyre was spinning up.

Assuming geostrophy, when $u = -\dfrac{g}{f}\dfrac{\partial h}{\partial y}$ and $v = \dfrac{g}{f}\dfrac{\partial h}{\partial x}$, ζ can also be computed from sea level data (Figure 4, red curve):

$$\zeta = \frac{\partial v}{\partial x} - \frac{\partial u}{\partial y} = \frac{g}{f}\left(\frac{\partial^2 h}{\partial x^2} + \frac{\partial^2 h}{\partial y^2}\right) = \frac{g}{f}\nabla^2 h$$

where u and v are the horizontal velocity components, h is the sea surface height, g – gravity, and $f = 2\omega\sin\varphi$ – Coriolis parameter.

Figure 4:
The relative vorticity averaged over the Zapiola Anticyclone (domain D in Figure 1) estimated from the depth-averaged velocities (blue curve) and from sea surface height data (red curve). This comparison confirms the barotropic character of the circulation.

3. Vorticity Balance

For the frictionless barotropic flow the vorticity equation can be expressed as

$$\zeta_t + \mathbf{u}\cdot\nabla\zeta + \beta v = fH^{-1}\mathbf{u}\cdot\nabla H + \rho^{-1}H^{-1}\nabla\times\boldsymbol{\tau}$$

where subscript indicates a partial derivative, $\beta = f_y$ is the meridional gradient of the planetary vorticity, H is depth, and τ is the wind stress. The left hand side of the equation represents the local change of ζ plus the relative and planetary vorticity fluxes; the right hand side of the equation represents the influence of bottom topography and the wind stress curl.

The sum of the terms on the left side of the vorticity equation is almost fully balanced by the topographic effect (correlation = 0.7) while the influence of the local wind stress curl is found negligible (Figure 5a). Both the relative (Figure 5b) and the planetary (Figure 5c) vorticity fluxes are found coherent with the time change of the anticyclone strength at some frequencies greater than ~0.5 cpy (Figure 5e). The relative vorticity flux is almost always positive into the domain D and thus maintains the anticyclonic circulation. The topographic effect (Figure 5d) is predominantly negative being a damping factor and counteracting the forcing of the absolute vorticity flux.
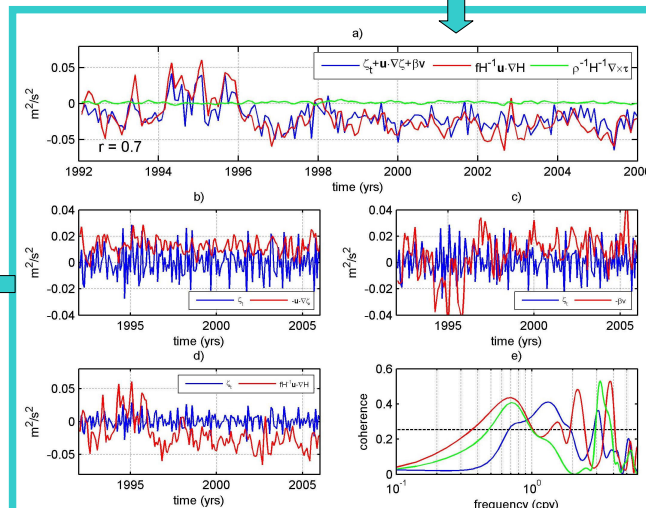

Figure 5:
The components of the vorticity equation integrated over the domain D in the Zapiola Anticyclone: (a) the sum of ζ_t and the absolute vorticity flux (blue curve) versus the topographic effect (red curve) and the wind stress curl (green curve); (b) the time series of ζ_t (blue curve) and the relative vorticity flux (red curve) and their coherence (e, blue curve); (c) the time series of ζ_t (blue curve) and the the planetary vorticity flux (red curve) and their coherence (e, red curve); (d) the time series of ζ_t (blue curve) and the topographic effect (red curve) and their coherence (e, green curve). The dashed straight line in e) is the 95% confidence limit.

4. Conclusions

a) The eddy-permitting ECCO2 simulations realistically reproduce the circulation of the Zapiola Anticyclone. The variability of the simulated anticyclone compares well with satellite altimetry observations.

b) The time change of the Zapiola Anticyclone strength is found to be determined by the balance between vorticity fluxes and the topographic effect while the impact of the local wind stress is negligible. Vorticity fluxes maintain the anticyclone while the topography acts as a damping factor.